

A CONSTANT PROPORTIONAL WEIR AND ORIFICE CONFIGURATION
FOR LATERAL FLOWS

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ABSTRACT

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The combination of a lateral orifice and weir housed in the side of a rectangular channel is examined, and a theoretical expression for the ratio of lateral outflow to channel flow is obtained. This derivation is used to predict a configuration having an approximately constant ratio of lateral outflow to channel flow, over a range of flows and flow depths.

The configuration comprised of a lateral weir and orifice has been termed a "Constant Proportional Lateral Weir and Orifice Configuration for Lateral Flows". The results of this study are presented in the form of design charts.

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TABLE OF CONTENTS

TABLE OF CONTENTS

| | Page |
|---|------|
| ABSTRACT..... | i |
| ACKNOWLEDGEMENTS..... | ii |
| LIST OF TABLES..... | iv |
| LIST OF FIGURES..... | v |
| NOTATION..... | vi |
| I INTRODUCTION..... | 1 |
| II THEORETICAL DERIVATION..... | 4 |
| 2.1 Theoretical Considerations..... | 5 |
| 2.1.1 Assumptions..... | 6 |
| 2.1.2 Channel Modification..... | 6 |
| 2.2 Flow Ratio Relationship..... | 10 |
| 2.2.1 Lateral Outflow..... | 10 |
| 2.2.2 Flow Ratio Equation..... | 15 |
| III SELECTION OF OPTIMUM CONFIGURATION..... | 18 |
| 3.1 Parameters and Ranges..... | 18 |
| 3.1.1 Algorithm..... | 19 |
| 3.2 Identification of Configurations..... | 20 |
| 3.2.1 Selection of Configuration..... | 21 |
| IV CHARACTERISTICS OF SELECTED CONFIGURATION..... | 22 |
| 4.1 Conclusions..... | 24 |
| REFERENCES..... | 25 |
| APPENDIX A - TABLES..... | 26 |
| APPENDIX B - FIGURES..... | 31 |
| APPENDIX C - EXPERIMENTAL SET-UP..... | 44 |

LIST OF TABLES

LIST OF TABLES

| Table | Description | Page |
|-------|---|------|
| 1 | Range of constant proportionality of various configurations with $S_1=0.1$ | 26 |
| 2 | Range of constant proportionality of various configurations with $S_1=0.15$ | 27 |
| 3 | Range of constant proportionality of various configurations with $S_1=0.2$ | 28 |
| 4 | Range of proportionality of selected configuration..... | 29 |
| 5 | Flow ratio of selected configuration for various length ratios and Froude numbers | 30 |

LIST OF FIGURES

LIST OF FIGURES

| Figure | Description | Page |
|--------|--|------|
| 1 | Generalized configuration | 31 |
| 2 | Configuration characteristics | 32 |
| 3 | Algorithm flowchart | 33 |
| 4 | Ratios algorithm | 34 |
| 5 | Ratio algorithm | 35 |
| 6 | Sample output | 36 |
| 7 | Comparison plot | 37 |
| 8 | Q_L/Q_1 vs Y_1 for selected configuration | 38 |
| 9 | Q_L/Q_1 vs Fr_1 for selected configuration [L/W=0.2] | 39 |
| 10 | Q_L/Q_1 vs Fr_1 for selected configuration [L/W=0.4] | 40 |
| 11 | Q_L/Q_1 vs Fr_1 for selected configuration [L/W=0.6] | 41 |
| 12 | Design chart | 42 |
| 13 | Design chart | 43 |
| 14 | Experimental set-up | 45 |

NOTATION

NOTATION

| Symbol | Description |
|--------|---|
| C_d | Discharge coefficient for two-dimensional flow layer. |
| dh | Incremental height of flow layer. |
| Fr_1 | Froude number of flow in channel. |
| g | Gravitational acceleration. |
| h_1 | Effective head for weir. |
| h_2 | Effective head for orifice. |
| H_1 | Depth from free surface to top edge of orifice. |
| H_2 | Depth from free surface to bottom of orifice. |
| H_0 | Height of orifice. |
| H_w | Depth from free surface to bottom of weir. |
| k | Constant of proportionality. |
| L | Length of lateral. |
| L/W | Length ratio. |
| N_1 | Velocity ratio at top of orifice. |
| N_2 | Velocity ratio at bottom of orifice. |
| N_w | Velocity ratio at bottom of weir. |
| Q_L | Lateral outflow. |
| Q_1 | Channel flow. |

| | |
|-------|--|
| S_1 | Bottom sill height. |
| S_2 | Middle sill height. |
| U | Normal component of jet velocity. |
| V_1 | Velocity in channel. |
| V_j | Jet velocity. |
| W | Width of channel. |
| Y_1 | Depth of flow in channel upstream of lateral. |
| Z | Width of channel contraction or height of channel bed elevation. |

CHAPTER I
INTRODUCTION

CHAPTER I

INTRODUCTION

A lateral, or side weir has been defined as "a free over-flow weir set into the side of a channel which allows part of the liquid to spill over the side when the surface of the flow in the channel rises above the weir crest", [Subramanya and Awasthy, 1972]. Likewise, a lateral orifice may be defined as an orifice set into the side of a channel allowing some portion of the flow to spill out laterally, the surface of the flow being at or above the topmost edge of the orifice. For any case where the flow surface is below the upper edge of the orifice, the situation becomes one of weir-flow. The present report is restricted to the discussion of rectangular lateral outlets in a rectangular channel, (Figure 1).

Approximate discharge relationships for lateral weirs have existed since the turn of the century, and more precise formulations have been the object of recent investigations [1,2,3]. The purpose of this report is to attempt to extend the most recent of these approaches [3], and derive a unique configuration of lateral weir and rectangular orifice which will produce a specific discharge characteristic.

The topic of this report stems from observation of the characteristic discharge relationships of both the rectangular orifice and the lateral weir. The forms of these relationships, $Q \sim h_1^{1.5}$ for the rectangular weir, and $Q \sim h_2^{0.5}$ for the orifice, suggest that there might be some configuration giving a combined discharge of the form

$$Q_L = kQ_1 \quad (1.1)$$

since h_1 and h_2 are functions of Y_1 , the depth of flow in the main channel. In equation 1.1,

Q_L = lateral flow

Q_1 = channel flow

k = some constant

over a usable range of depths of flow (Figure 2). An allowable deviation of $\pm 2.5\%$ from the design flow ratio Q_L/Q_1 , was adopted as the criterion for choosing suitable configurations, (Figure 2).

For the purposes of this report, a lateral weir and orifice configuration possessing the above characteristics is termed a 'Constant Proportional Lateral Weir and Orifice Configuration', or a 'Lateral'. A combination

of this type would have applications in the fields of flood protection, land drainage, irrigation and urban water works.

Figure 1 indicates the general set-up which will be considered, as well as the convention of notation to be used throughout the report.

CHAPTER II

THEORETICAL DERIVATION

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THEORETICAL DERIVATION

In order to predict an optimum lateral configuration which will produce a relatively constant flow ratio over some range of flow depths, a functional relationship between depth of flow and lateral outflow is formulated as follows:

$$Q_L/Q_1 = f(S_1, H_0, S_2, L/W, Fr_1, Y_1)$$

where

Q_L/Q_1 = ratio of lateral outflow to channel flow

S_1 = bottom sill height

H_0 = orifice height

S_2 = middle sill height

L/W = ratio of lateral length to channel width

Fr_1 = Froude number of channel flow

Y_1 = initial depth of flow in channel

The parameters S_1 , H_0 , S_2 and L/W describe the physical configuration of the lateral (Figure 1), while Fr_1 and Y_1 are governed by the channel flow Q_1 as well as L/W .

Once a theoretical relationship between the above parameters and the flow ratio has been derived, each of

the parameters can be varied in order to assess their individual effect on the flow ratio. Those parameters describing the physical configuration of the lateral have been nondimensionalized by dividing them by the actual maximum depth of channel flow, $Y'_{1\max}$, as follows

$$Y_1 = Y'_1 / Y'_{1\max}$$

$$S_1 = S'_1 / Y'_{1\max}$$

$$H_0 = H'_0 / Y'_{1\max}$$

$$S_2 = S'_2 / Y'_{1\max}$$

where the primes (') indicate actual values. In effect these geometric parameters are expressed as a percentage of the maximum flow depth in the channel.

2.1 THEORETICAL CONSIDERATIONS

The approach used in deriving a theoretical relationship for the flow ratio necessitates the assumption of certain conditions with regards to the flow, both through the lateral and in the channel, [3]. These either approximate the actual conditions occurring, or are easily imposed by channel geometry modifications.

2.1.1 ASSUMPTIONS

The flow, both through the rectangular orifice and over the weir, is assumed to be two-dimensional in nature. In other words, changes in the channel velocity V_1 , and in the lateral flow velocity U , occur only within the plane of the incremental layer dh , (Figure 1). Also, the pressure distribution at any section of the lateral is assumed to be hydrostatic, hence the normal velocity component U , through any layer dh is equal to $\sqrt{2gh}$, where h is the depth of the layer below the free surface. Furthermore, the energy loss in the short reach corresponding to the weir span is assumed to be negligible.

Further conditions assumed are: the free surface of the channel flow is horizontal over the length of the lateral (a condition easily imposed as described in section 2.1.2), the flow upstream of the lateral is subcritical, and the maximum length of the lateral is limited to the channel width.

2.1.2 CHANNEL MODIFICATION

The condition of a horizontal free surface in the channel along the length of the lateral can be imposed by either of two methods. The channel side opposite the lateral

can be moved inward, or the channel bed can be gradually raised towards the downstream end of the lateral. Both these modifications serve to reduce the area of flow at the downstream end of the lateral, keeping the channel velocity constant along the length of the lateral and thus imposing a horizontal free surface if the flow is consistent with the assumptions stated earlier.

Because the bottom sill may be of relatively low height, the side contraction is proposed as the more practical of the two for the configuration described. It should be noted however, that the side contraction may cause a higher lateral velocity U , than predicted, thus violating one of the assumptions made earlier. This effect should be investigated experimentally to ascertain the extent of influence.

The width of the contraction Z , (Figure 1) necessary to impose a horizontal free surface can be found as follows:

assuming constant specific energy over the length of the lateral

$$Y_1 + \frac{V_1^2}{2g} = Y_2 + \frac{V_2^2}{2g}$$

and noting that for a horizontal free surface and bed

$$Y_1 = Y_2$$

$$V_1^2 = V_2^2$$

and

$$\frac{Q_1^2}{(W_1 Y_1)^2} = \frac{Q_2^2}{(W_2 Y_2)^2}$$

also, since

$$Q_2 = Q_1 - Q_L$$

$$\frac{Q_1}{W_1} = \frac{Q_1 - Q_L}{W_2}$$

or

$$\frac{W_2}{W_1} = \frac{Q_1 - Q_L}{Q_1}$$

$$\frac{W_1 - Z}{W_1} = \frac{Q_1 - Q_L}{Q_1}$$

or

$$\frac{Z}{W_1} = \frac{Q_L}{Q_1}$$

(2.1)

where W is the channel width, Z is the width of contraction, and subscripts 1 and 2 refer to upstream and downstream values respectively.

It should be noted that the desired lateral configuration will have Q_L/Q_1 constant and therefore, since the channel width is fixed, the side contraction width will also be constant over the range of proportionality.

The height of the bottom rise above the channel bed necessary to maintain a horizontal free surface over the length of the lateral can be similarly shown to be

$$\frac{Z}{Y_1} = \frac{Q_L}{Q_1} \quad (2.2)$$

where Z is the height required at the downstream end of a linear rise along the channel bed, and Y_1 is the initial (upstream) depth of flow in the channel. This configuration as mentioned previously, provides an alternate method of imposing the horizontal free surface condition over the length of the lateral.

2.2 FLOW RATIO RELATIONSHIP

The theoretical flow ratio relationship can be derived by first obtaining an expression for the lateral outflow as a function of the relevant geometric and hydrodynamic parameters [3,5]. The lateral outflow divided by the channel flow then yields the required flow ratio.

2.2.1 LATERAL OUTFLOW

An expression for the lateral outflow can be obtained by summing the discharges of the incremental layers (height dh , length L) over the total depth of the lateral weir and orifice, the elevation of the free surface is assumed to be constant along the length of the lateral, (See Figure 1).

The discharge coefficient C_d , for each layer is assumed to be dependant upon the velocity ratio N , ($N = V_1/V_j$, where V_1 is the channel velocity, and V_j is the jet velocity), and the ratio L/W . The channel velocity is assumed to be subcritical, and the normal component U , of the jet velocity of a layer equal to $\sqrt{2gh}$, h being the depth of the layer below the free surface. For any layer then, the jet velocity is

$$V_j = \sqrt{V_1^2 + 2gh}$$

and the velocity ratio N , for each layer is then

$$N = \frac{V_1}{\sqrt{V_1^2 + 2gh}} \quad (2.3)$$

C_d is found to be approximated by the following expression [3],

$$C_d = 0.61 + C_1 N^2 + C_2 N^4 + C_3 N^6 \quad (2.4)$$

for $0 < L/W \leq 1$

and $0 < N \leq 1$

in which

$$C_1 = -0.538 + 0.254L/W$$

$$C_2 = 0.058 + 0.234L/W$$

$$C_3 = -0.129 - 0.489L/W$$

Noting that C_d will vary from layer to layer, and that the area of each layer is Ldh , the discharge of a layer will be $C_d V_j Ldh$. The total discharge over some range of depth A to B , will then be

$$Q_L = \int_B^A C_d V_j Ldh \quad (2.5)$$

where the limit A, in the case now being examined, is the free surface and B is the depth of the lateral.

For the configuration consisting of a weir and orifice as shown in Figure 1, equation 2.5 becomes

$$Q_L = \int_{H_1}^{H_2} C_d V_j L dh + \int_0^{H_W} C_d V_j L dh \quad (2.6)$$

from equation 2.3

$$h = \frac{1}{2g} \left[\frac{V_1^2}{N^2} - V_1^2 \right] \quad (2.7)$$

and

$$dh = \frac{-V_1^2}{gN^3} dN \quad (2.8)$$

Reevaluating the limits of integration for equation 2.6 in terms of N,

$$H_1: N_1 = \frac{V_1}{\sqrt{V_1^2 + 2gH_1}} \quad (2.9a)$$

$$H_2: N_2 = \frac{V_1}{\sqrt{V_1^2 + 2gH_2}} \quad (2.9b)$$

$$H_W: N_W = \frac{V_1}{\sqrt{V_1^2 + 2gH_W}} \quad (2.9c)$$

$$0: N_{\text{surface}} = \frac{V_1}{\sqrt{V_1^2 + 2g(0)}} = 1.0 \quad (2.9d)$$

Substituting equations 2.8 and 2.9 into 2.6,

$$Q_L = \int_{N_1}^{N_2} C_d L \left[\frac{-V_1^3}{gN^4} \right] dN + \int_1^{N_W} C_d L \left[\frac{-V_1^3}{gN^4} \right] dN$$

Replacing C_d with equation 2.4, we obtain,

$$Q_L = \int_{N_2}^{N_1} \left[\frac{0.611}{N^4} + \frac{C_1}{N^2} + C_2 + C_3 N^2 \right] \frac{LV_1^3}{g} dN + \dots$$

$$\dots + \int_{N_W}^1 \left[\frac{0.611}{N^4} + \frac{C_1}{N^2} + C_2 + C_3 N^2 \right] \frac{LV_1^3}{g} dN$$

Solving,

$$\begin{aligned} Q_L = \frac{LV_1^3}{g} & \left[\left[\frac{-0.203}{N_1^3} - \frac{C_1}{N_1} + C_2 N_1 + \frac{C_3 N_1^3}{3} \right] - \dots \right. \\ & \left. \dots - \left[\frac{-0.203}{N_2^3} - \frac{C_1}{N_2} + C_2 N_2 + \frac{C_3 N_2^3}{3} \right] + \dots \right. \\ & \left. \dots + \frac{LV_1^3}{g} \left[-0.203 \left[1 - \frac{1}{N_W^3} \right] - C_1 \left[1 - \frac{1}{N_W} \right] + \dots \right. \right. \\ & \left. \left. \dots + C_2 \left[1 - N_W \right] + \frac{C_3}{3} \left[1 - N_W^3 \right] \right] \right] \end{aligned}$$

Simplifying,

$$Q_L = \frac{LV_1^3}{g} \left[0.203 \left[\frac{1}{N_2^3} - \frac{1}{N_1^3} \right] + C_1 \left[\frac{1}{N_2} - \frac{1}{N_1} \right] - \dots \right]$$

$$\begin{aligned}
 & \dots - C_2 \left[N_2 - N_1 \right] - \frac{C_3}{3} \left[N_2^3 - N_1^3 \right] + \dots \\
 & \dots + \frac{LV_1}{g} \left[1 - N_W^3 \right] \left[\frac{C_3 + 0.203}{3 N_W^3} \right] + \dots \\
 & \dots + \left[1 - N_W \right] \left[\frac{C_2 - C_1}{N_W} \right] \quad (2.10)
 \end{aligned}$$

The first part of equation 2.10 represents the flow through the lateral orifice for any $Y_1 \geq S_1 + H_0$. the second portion represents the flow over the lateral weir for any $Y_1 \geq S_1 + H_0 + S_2$.

2.2.2 FLOW RATIO EQUATION

Equations 2.9 in terms of Y_1 and Fr_1 become

$$N_1 = \frac{Fr_1 \sqrt{Y_1}}{\sqrt{Fr_1^2 Y_1 + Y_1 - S_1 - H_0}}$$

$$N_2 = \frac{Fr_1 \sqrt{Y_1}}{\sqrt{Fr_1^2 Y_1 + Y_1 + S_1}}$$

$$N_W = \frac{Fr_1 Y_1}{\sqrt{Fr_1^2 Y_1 + Y_1 - S_1 - S_2 - H_0}}$$

N_1 and N_2 for $Y_1 \geq S_1 + H_0$

& N_W for $Y_1 \geq S_1 + S_2 + H_0$.

An expression for the flow ratio can now be obtained
in terms of L/W , Fr_1 and Y_1

$$\begin{aligned} Q_L/Q_1 &= \frac{2LFr_1^2}{W} \left[0.203 \left[\frac{\sqrt{Fr_1^2 Y_1 + Y_1 - S_1}}{Fr_1 \sqrt{Y_1}} \right]^3 - \dots \right. \\ &\dots - \left. \left[\frac{\sqrt{Fr_1^2 Y_1 + Y_1 - S_1 - H_0}}{Fr_1 \sqrt{Y_1}} \right]^3 \right] + \dots \\ &\dots + C_1 \left[\frac{\sqrt{Fr_1^2 Y_1 + Y_1 - S_1}}{Fr_1 \sqrt{Y_1}} - \frac{\sqrt{Fr_1^2 Y_1 + Y_1 - S_1 - H_0}}{Fr_1 \sqrt{Y_1}} \right] - \dots \\ &\dots - C_2 \left[\frac{Fr_1 \sqrt{Y_1}}{\sqrt{Fr_1^2 Y_1 + Y_1 - S_1}} - \frac{Fr_1 \sqrt{Y_1}}{\sqrt{Fr_1^2 Y_1 + Y_1 - S_1 - H_0}} \right] - \dots \\ &\dots - \frac{C_3}{3} \left[\left[\frac{Fr_1 \sqrt{Y_1}}{\sqrt{Fr_1^2 Y_1 + Y_1 - S_1}} \right]^3 - \left[\frac{Fr_1 \sqrt{Y_1}}{\sqrt{Fr_1^2 Y_1 + Y_1 - S_1 - H_0}} \right]^3 \right] + \dots \end{aligned}$$

$$\begin{aligned}
& \dots + \frac{2LFr_1^2}{W} \left[1 - \frac{Fr_1 \sqrt{Y_1}}{\sqrt{Fr_1^2 Y_1 + Y_1 - S_1 - S_2 - H_0}} \right]^3 \dots \\
& \dots \left[\frac{C_3 + 0.203}{3} \left[\frac{\sqrt{Fr_1^2 Y_1 + Y_1 - S_1 - S_2 - H_0}}{Fr_1 \sqrt{Y_1}} \right]^3 \right] + \dots \\
& \dots + \left[1 - \frac{Fr_1 \sqrt{Y_1}}{\sqrt{Fr_1^2 Y_1 + Y_1 - S_1 - S_2 - H_0}} \right] \dots \\
& \dots \left[\frac{C_2 + C_1 \sqrt{Fr_1^2 Y_1 + Y_1 - S_1 - S_2 - H_0}}{Fr_1 \sqrt{Y_1}} \right] \quad (2.11)
\end{aligned}$$

The portion of the flow ratio equation (2.11) governing the orifice flow (the five lines on the preceding page) is valid for $Y_1 \geq S_1 + H_0$. The latter portion which governs the weir flow is valid for $Y_1 \geq S_1 + H_0 + S_2$.

CHAPTER III

SELECTION OF OPTIMUM CONFIGURATION

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SELECTION OF OPTIMUM CONFIGURATION

Although it is possible to find the optimum configuration by analytical methods, the simplest approach is to create a computer algorithm to solve equation 2.11 for various configurations and flow conditions.

3.1 PARAMETERS AND RANGES

The parameters to be varied in the algorithm are identified in Figure 1. A particular configuration can be uniquely described by its bottom sill height S_1 , its orifice height H_0 , its middle sill height S_2 , and the lateral length to channel width ratio L/W . Any one configuration may be subjected to an infinite number of flow conditions, described by the depth of flow Y , and the Froude number of the flow in the main channel Fr_1 .

The range of L/W was limited to $0 \leq L/W \leq 1$ as in [3]. The ranges of S_1 , H_0 , and S_2 were between 0.1 and a maximum determined by the condition that some weir flow must occur. In other words, $S_1 + H_0 + S_2$ must be less than the maximum depth of flow in the channel.

The range of flow conditions examined are as follows:

- i) The depth of flow Y_1 , may vary between the bottom of the middle sill ($Y_1 = S_1 + H_0$) and the maximum depth of flow ($Y_1 = 1$).
- ii) The Froude number of the flow in the channel can vary from 0.1 to 0.9.

Although these are the ranges of the specific parameters which were examined, equation 2.11 is not necessarily valid over all of these values. This will be discussed further in Chapter IV.

3.1.1 ALGORITHM

Having identified the parameters and their ranges, a flow diagram of the algorithm to be used was drawn (Figure 3). The program was written using BASIC-PLUS language on a PDP 11/70 computer.

The program consists of a subroutine which calculates the flow ratio by equation 2.11, and various devices within the main program to increment Y_1 and Fr_1 for a particular configuration. The original program 'Ratios' shown in Figure 4, computes the flow ratio for a given S_1 , H_0 , S_2 over the allowable ranges of Y_1 and Fr_1 . If the flow ratio

varies by more than $\pm 2.5\%$ over any portion of the range of Y_1 then the program cycles to a new flow condition, indicating in the output that the constant proportionality criterion has been exceeded.

'Ratios' was modified (Figure 5) to compute the variation of Fr_1 for a particular design flow ratio and configuration.

Sample partial outputs of the two algorithms are shown in Figure 6. A further modification of the basic algorithm was undertaken to obtain a graphical output of the flow ratio vs Y_1 for a particular configuration and flow condition, shown in Figure 7.

3.2 IDENTIFICATION OF SUITABLE CONFIGURATIONS

It was felt that there would be one 'class' of configurations which would exhibit the desired characteristics. In order to identify this 'class', preliminary sets of flow ratio, Y_1 , and Fr_1 were output, comprising a large number of various configurations. A portion of this output is shown in Tables 1, 2 and 3.

This preliminary output indicated that the

greatest range of Y_1 for Q_L/Q_1 varying less than $\pm 2.5\%$ occurred in configurations having $S_1=S_2$.

This class of configurations was then examined in greater detail (the increments of Y_1 being reduced and a greater number of configurations examined).

3.2.1. SELECTED CONFIGURATION

The optimum configuration to be chosen from the data in Tables 1, 2 and 3, must meet all the previously mentioned criteria, and should also exhibit the constant proportioning characteristic over all flow conditions examined. This latter condition excludes from acceptance those configurations having large ranges of constant proportionality at some flow conditions, and small ranges at other flows.

It should be noted that those configurations in Tables 1, 2 and 3 for which the range of constant proportionality is less than the nondimensional middle sill height S_2 , do not produce any flow over the weir portion of the lateral, before exceeding the allowable flow ratio variation. Configurations in Tables 1, 2 and 3 shown as having a zero range of proportionality in effect have a flow ratio greater than unity for orifice flow alone.

CHAPTER IV

CHARACTERISTICS OF SELECTED CONFIGURATION

CHAPTER IV

CHARACTERISTICS OF SELECTED CONFIGURATION

Upon inspection of tables 1, 2, and 3 it is evident that the configuration having $S_1=0.1$, $H_0=0.45$, and $S_2=0.1$ exhibits the largest range of constant proportionality over the flow conditions examined. This is shown graphically by a comparison computer plot of Q_L/Q_1 vs Y_1 for two selected configurations (Figure 7). The flow ratios for the selected configuration are shown in Figure 8 for various values of L/W and Froude numbers.

This selected configuration is only the optimum for an allowable deviation from a design flow ratio of $\pm 2.5\%$. A larger or smaller allowable deviation would result in a different optimum configuration being chosen.

The range of constant proportionality of the selected configuration for various values of L/W and Fr_1 is shown in Table 4. Values of the flow ratio for various L/W and Fr_1 generated by the 'Ratios' algorithm (Figure 4) are presented in Table 5, and shown graphically in the form of design charts by Figures 12 and 13.

The original assumption of a horizontal free surface was obtained by maintaining a constant rate of flow per

unit width of the main channel. To this end, the area of flow in the main channel was reduced as the lateral flow was subtracted from the channel flow. This implies or requires that the channel flow velocity remains constant over the length of the lateral, or that the channel Froude number is constant over the length of the lateral. The application of this condition is shown by the plot of the flow ratio vs the channel Froude number over the entire range of Y_1 , (Figures 9, 10, and 11) for three values of L/W . These plots show the negligible variation of Fr_1 for a design value of Q_L/Q_1 .

It is apparent that in the study undertaken in [3], no effort was made to impose the horizontal free surface condition along the length of the lateral. Instead, the reference depth of flow along the weir was assumed to be the depth at its mid-point. It was stated that the theoretical lateral discharge was approximately 5% greater than the actual. This discrepancy was said to be due to the assumption that the velocity distribution in the channel was uniform, (in other words no account was made for the non-uniform velocity distribution which actually occurred). In the present study, the same assumptions and theoretical approach were used, hence it may therefore be anticipated that equation 2.11 will predict a flow ratio slightly higher than will actually be measured.

In the event that a side contraction is used to impose the horizontal free surface condition, the resulting increase in the lateral jet velocity may offset the above-mentioned over-estimation of the flow ratio. The use of a bottom contraction would have little effect on the jet velocity, but might result in an even greater over-estimation of the flow ratio, due to a more non-uniform velocity distribution in the channel.

4.1 CONCLUSIONS

The following conclusions can be drawn on the basis of the present study.

For subcritical flow in a rectangular channel of width W , carrying a discharge Q_1 , at a depth Y_1 , a 'lateral' of length L can be designed to provide a lateral discharge Q_L , which is a linear function of the channel discharge Q_1 . In order to achieve this over a range of Y_1 , one must properly choose the geometric variables S_1 , H_0 and S_2 of the 'lateral'. The water surface over the length of the 'lateral' must also be kept horizontal. This may be accomplished by either uniformly narrowing the channel width, or uniformly raising the channel bed over the reach of channel spanning the 'lateral'.

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APPENDIX A

TABLES

TABLE 1 RANGE OF CONSTANT PROPORTIONALITY OF
CONFIGURATIONS WITH $S_1=0.10$ [Expressed as
a percentage of the maximum flow depth]

| S_1 | H_0 | S_2 | L/W= | | | | | | | | |
|-------|-------|-------|-------------------|----|----|------|----|----|------|----|----|
| | | | 0.25 | | | 0.50 | | | 0.75 | | |
| | | | Fr ₁ = | | | | | | | | |
| | | | .1 | .4 | .7 | .1 | .4 | .7 | .1 | .4 | .7 |
| .10 | .30 | .10 | 26 | 28 | 30 | 0 | 27 | 30 | 0 | 11 | 30 |
| .10 | .30 | .15 | 11 | 12 | 14 | 0 | 11 | 13 | 0 | 10 | 13 |
| .10 | .30 | .20 | 11 | 12 | 14 | 0 | 11 | 13 | 0 | 10 | 13 |
| .10 | .30 | .25 | 11 | 12 | 14 | 0 | 11 | 13 | 0 | 10 | 13 |
| .10 | .35 | .10 | 31 | 35 | 35 | 0 | 32 | 35 | 0 | 32 | 34 |
| .10 | .35 | .15 | 11 | 13 | 15 | 0 | 12 | 14 | 0 | 11 | 13 |
| .10 | .35 | .20 | 11 | 13 | 15 | 0 | 12 | 14 | 0 | 11 | 13 |
| .10 | .35 | .25 | 11 | 13 | 15 | 0 | 12 | 14 | 0 | 11 | 13 |
| .10 | .40 | .10 | 35 | 37 | 40 | 0 | 36 | 40 | 0 | 35 | 39 |
| .10 | .40 | .15 | 12 | 14 | 17 | 0 | 13 | 15 | 0 | 12 | 14 |
| .10 | .40 | .20 | 12 | 14 | 16 | 0 | 13 | 15 | 0 | 12 | 14 |
| .10 | .40 | .25 | 12 | 14 | 16 | 0 | 13 | 15 | 0 | 12 | 14 |
| .10 | .45 | .10 | 40 | 43 | 45 | 0 | 41 | 45 | 0 | 40 | 45 |
| .10 | .45 | .15 | 13 | 15 | 19 | 0 | 14 | 16 | 0 | 13 | 15 |
| .10 | .45 | .20 | 13 | 15 | 17 | 0 | 15 | 17 | 0 | 13 | 15 |
| .10 | .45 | .25 | 13 | 15 | 17 | 0 | 14 | 16 | 0 | 13 | 15 |
| .10 | .50 | .10 | 40 | 40 | 40 | 0 | 40 | 40 | 0 | 40 | 40 |
| .10 | .50 | .15 | 13 | 16 | 22 | 0 | 14 | 18 | 0 | 13 | 17 |
| .10 | .50 | .20 | 13 | 15 | 18 | 0 | 14 | 17 | 0 | 13 | 16 |
| .10 | .50 | .25 | 13 | 15 | 18 | 0 | 14 | 17 | 0 | 13 | 16 |

TABLE 2 RANGE OF CONSTANT PROPORTIONALITY OF
CONFIGURATIONS WITH $S_1=0.15$ [Expressed as
a percentage of the maximum flow depth]

| S_1 | H_0 | S_2 | L/W= 0.25 | | | 0.50 | | | 0.75 | | |
|-------|-------|-------|-------------------|----|----|------|----|----|------|----|----|
| | | | Fr ₁ = | | | | | | | | |
| | | | .1 | .4 | .7 | .1 | .4 | .7 | .1 | .4 | .7 |
| .15 | .30 | .10 | 21 | 20 | 15 | 0 | 21 | 18 | 0 | 22 | 20 |
| .15 | .30 | .15 | 14 | 31 | 30 | 0 | 15 | 32 | 0 | 14 | 33 |
| .15 | .30 | .20 | 14 | 16 | 19 | 0 | 15 | 18 | 0 | 14 | 16 |
| .15 | .30 | .25 | 14 | 16 | 19 | 0 | 15 | 18 | 0 | 14 | 16 |
| .15 | .35 | .10 | 24 | 23 | 19 | 0 | 25 | 22 | 0 | 25 | 24 |
| .15 | .35 | .15 | 15 | 35 | 35 | 0 | 16 | 37 | 0 | 15 | 36 |
| .15 | .35 | .20 | 15 | 17 | 20 | 0 | 16 | 18 | 0 | 15 | 17 |
| .15 | .35 | .25 | 15 | 17 | 20 | 0 | 16 | 18 | 0 | 15 | 17 |
| .15 | .40 | .10 | 27 | 27 | 23 | 0 | 29 | 26 | 0 | 28 | 28 |
| .15 | .40 | .15 | 16 | 38 | 41 | 0 | 37 | 42 | 0 | 15 | 40 |
| .15 | .40 | .20 | 15 | 18 | 21 | 0 | 16 | 29 | 0 | 15 | 18 |
| .15 | .40 | .25 | 15 | 18 | 21 | 0 | 16 | 19 | 0 | 15 | 18 |
| .15 | .45 | .10 | 31 | 32 | 28 | 0 | 32 | 30 | 0 | 32 | 32 |
| .15 | .45 | .15 | 40 | 40 | 40 | 0 | 40 | 40 | 0 | 17 | 40 |
| .15 | .45 | .20 | 16 | 18 | 23 | 0 | 17 | 20 | 0 | 16 | 19 |
| .15 | .45 | .25 | 16 | 18 | 22 | 0 | 17 | 20 | 0 | 16 | 19 |
| .15 | .50 | .10 | 34 | 35 | 32 | 0 | 35 | 35 | 0 | 35 | 35 |
| .15 | .50 | .15 | 35 | 35 | 35 | 0 | 35 | 35 | 0 | 35 | 35 |
| .15 | .50 | .20 | 17 | 19 | 25 | 0 | 18 | 21 | 0 | 19 | 20 |
| .15 | .50 | .25 | 17 | 19 | 23 | 0 | 18 | 21 | 0 | 17 | 20 |

TABLE 3 RANGE OF CONSTANT PROPORTIONALITY OF
CONFIGURATIONS WITH $S_1=0.20$ [Expressed as
a percentage of the maximum flow depth]

| S_1 | H_0 | S_2 | $L/W=$ | | | | | | | | | |
|-------|-------|-------|---------|----|----|------|----|----|------|----|----|----|
| | | | 0.25 | | | 0.50 | | | 0.75 | | | |
| | | | $Fr_1=$ | .1 | .4 | .7 | .1 | .4 | .7 | .1 | .4 | .7 |
| .20 | .30 | .10 | | 15 | 4 | 3 | 15 | 14 | 3 | 0 | 15 | 3 |
| .20 | .30 | .15 | | 26 | 4 | 3 | 26 | 25 | 3 | 0 | 26 | 3 |
| .20 | .30 | .20 | | 18 | 4 | 3 | 18 | 19 | 3 | 0 | 18 | 3 |
| .20 | .30 | .25 | | 18 | 4 | 3 | 18 | 19 | 3 | 0 | 18 | 3 |
| .20 | .35 | .10 | | 18 | 15 | 4 | 0 | 17 | 5 | 0 | 18 | 13 |
| .20 | .35 | .15 | | 29 | 27 | 4 | 0 | 29 | 5 | 0 | 30 | 27 |
| .20 | .35 | .20 | | 19 | 38 | 4 | 0 | 20 | 5 | 0 | 18 | 23 |
| .20 | .35 | .25 | | 19 | 21 | 4 | 0 | 20 | 5 | 0 | 18 | 21 |
| .20 | .40 | .10 | | 21 | 18 | 11 | 0 | 20 | 15 | 0 | 21 | 17 |
| .20 | .40 | .15 | | 31 | 31 | 25 | 0 | 33 | 28 | 0 | 32 | 31 |
| .20 | .40 | .20 | | 19 | 40 | 40 | 0 | 21 | 40 | 0 | 19 | 40 |
| .20 | .40 | .25 | | 19 | 22 | 26 | 0 | 20 | 24 | 0 | 19 | 22 |
| .20 | .45 | .10 | | 24 | 21 | 16 | 0 | 23 | 19 | 0 | 24 | 21 |
| .20 | .45 | .15 | | 34 | 35 | 29 | 0 | 35 | 33 | 0 | 35 | 35 |
| .20 | .45 | .20 | | 20 | 35 | 35 | 0 | 21 | 35 | 0 | 19 | 35 |
| .20 | .45 | .25 | | 20 | 22 | 27 | 0 | 21 | 24 | 0 | 19 | 23 |
| .20 | .50 | .10 | | 27 | 24 | 19 | 0 | 26 | 22 | 0 | 27 | 24 |
| .20 | .50 | .15 | | 30 | 30 | 30 | 0 | 30 | 30 | 0 | 30 | 30 |
| .20 | .50 | .20 | | 21 | 30 | 30 | 0 | 23 | 30 | 0 | 20 | 30 |
| .20 | .50 | .25 | | 20 | 23 | 29 | 0 | 22 | 25 | 0 | 20 | 24 |

TABLE 4 RANGE OF PROPORTIONALITY OF SELECTED
CONFIGURATION [EXPRESSED AS A PERCENTAGE
OF MAXIMUM FLOW DEPTH]

| L/W | Fr ₁ = .1 .2 .3 .4 .5 .6 .7 | | | | | | |
|-----|--|----|----|----|----|----|----|
| | | | | | | | |
| .20 | 40 | 41 | 42 | 43 | 44 | 45 | 45 |
| .30 | 40 | 41 | 41 | 43 | 44 | 45 | 45 |
| .40 | 0 | 40 | 41 | 42 | 43 | 45 | 45 |
| .50 | 0 | 40 | 41 | 41 | 43 | 44 | 45 |
| .60 | 0 | 40 | 40 | 41 | 42 | 44 | 45 |
| .70 | 0 | 0 | 40 | 41 | 42 | 44 | 45 |

TABLE 5 FLOW RATIO OF SELECTED CONFIGURATION
FOR VARIOUS CHANNEL FROUDE NO'S AND
LENGTH RATIOS [EXPRESSED AS A PERCENTAGE]

| | $Fr_1 =$.1 .2 .3 .4 .5 .6 .7 .8 | | | | | | | |
|-----|----------------------------------|----|----|----|----|----|----|----|
| L/W | | | | | | | | |
| .20 | 60 | 29 | 19 | 14 | 10 | 8 | 7 | 6 |
| .25 | 75 | 35 | 23 | 17 | 13 | 10 | 9 | 8 |
| .30 | 90 | 44 | 28 | 21 | 16 | 13 | 11 | 9 |
| .35 | | 51 | 33 | 25 | 19 | 15 | 13 | 11 |
| .40 | | 60 | 39 | 28 | 22 | 18 | 15 | 13 |
| .45 | | 67 | 44 | 33 | 25 | 21 | 17 | 15 |
| .50 | | 75 | 49 | 36 | 28 | 23 | 19 | 17 |
| .55 | | 87 | 54 | 40 | 32 | 26 | 22 | 19 |
| .60 | | 90 | 60 | 44 | 35 | 29 | 24 | 21 |
| .65 | | 97 | 64 | 48 | 38 | 31 | 27 | 23 |
| .70 | | | 70 | 52 | 41 | 34 | 29 | 25 |
| .75 | | | 75 | 56 | 45 | 37 | 32 | 27 |

APPENDIX B

FIGURES

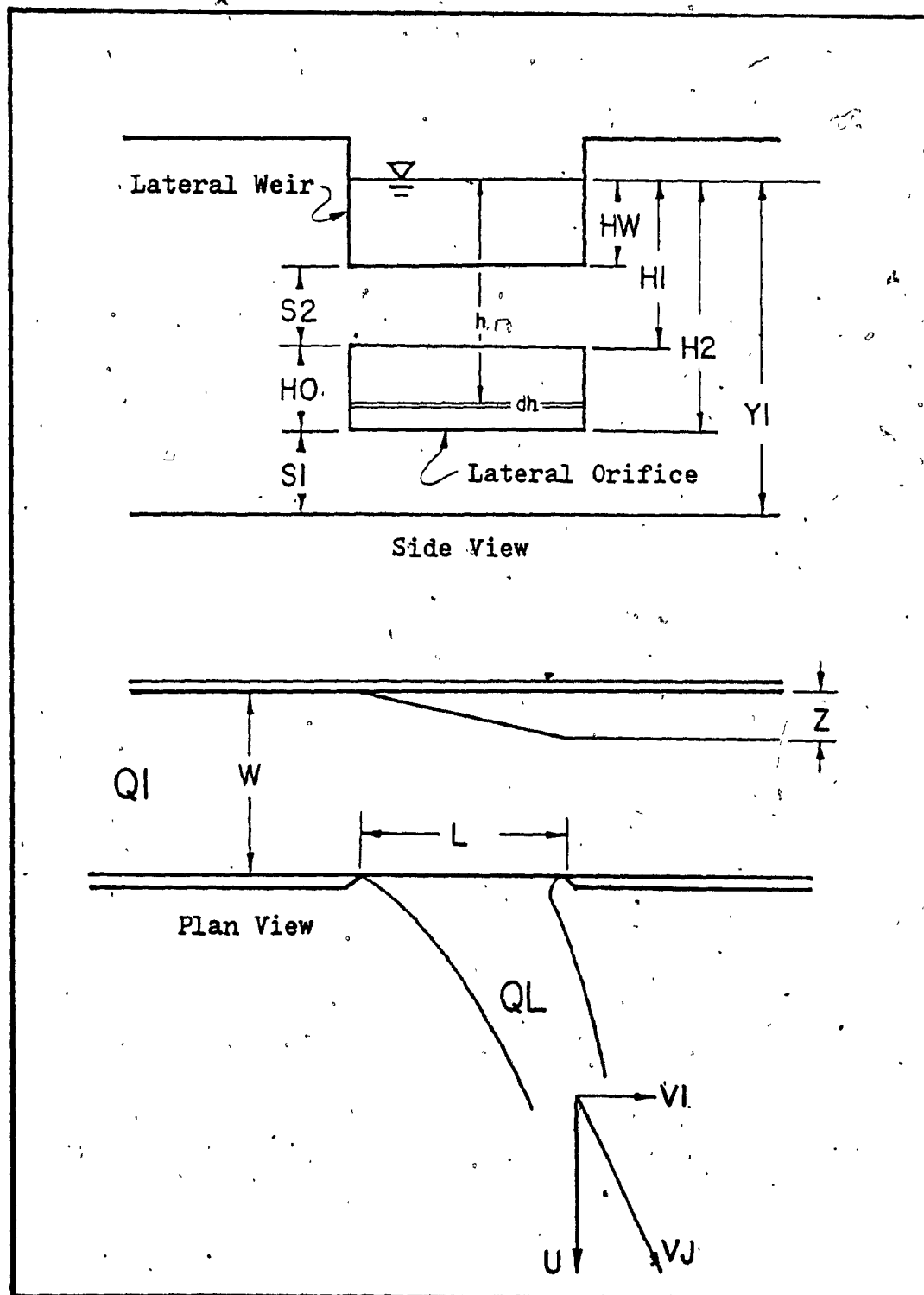


FIGURE 1 GENERALIZED CONFIGURATION

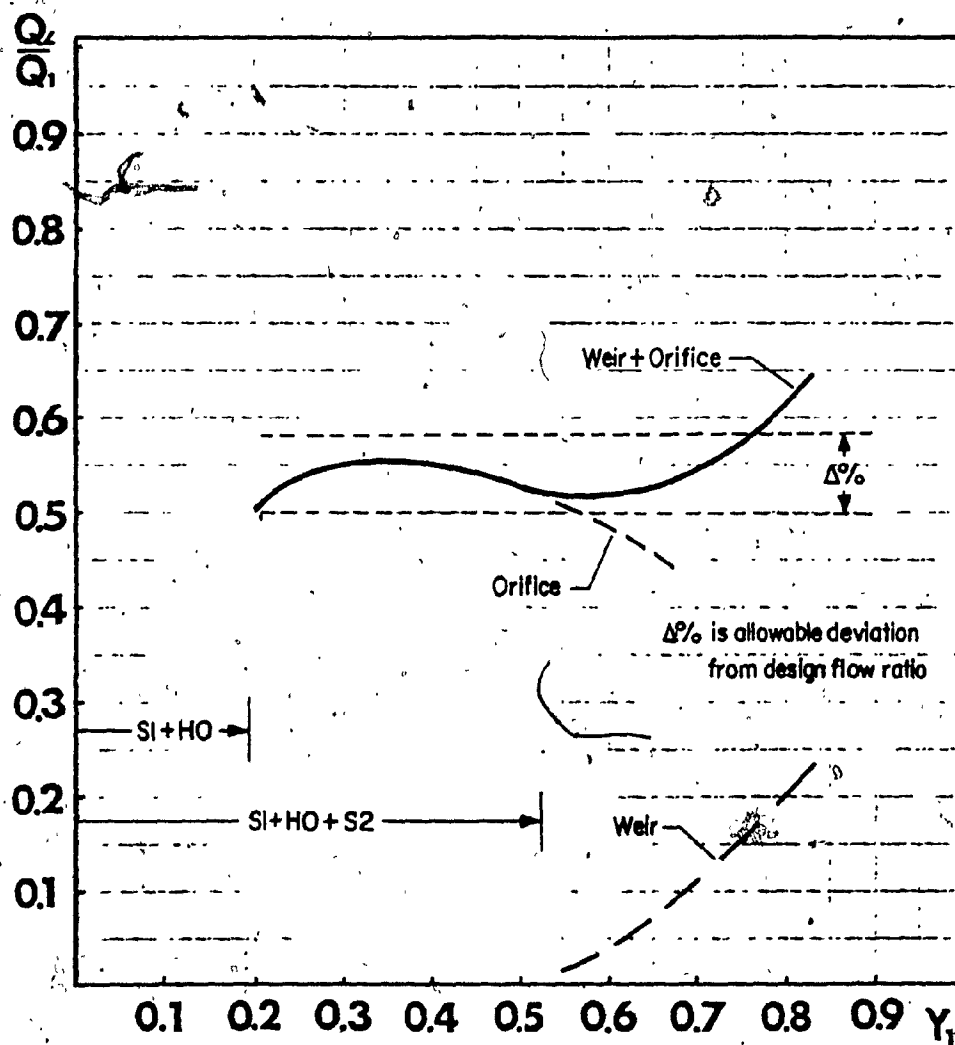


FIGURE 2 CONFIGURATION CHARACTERISTICS

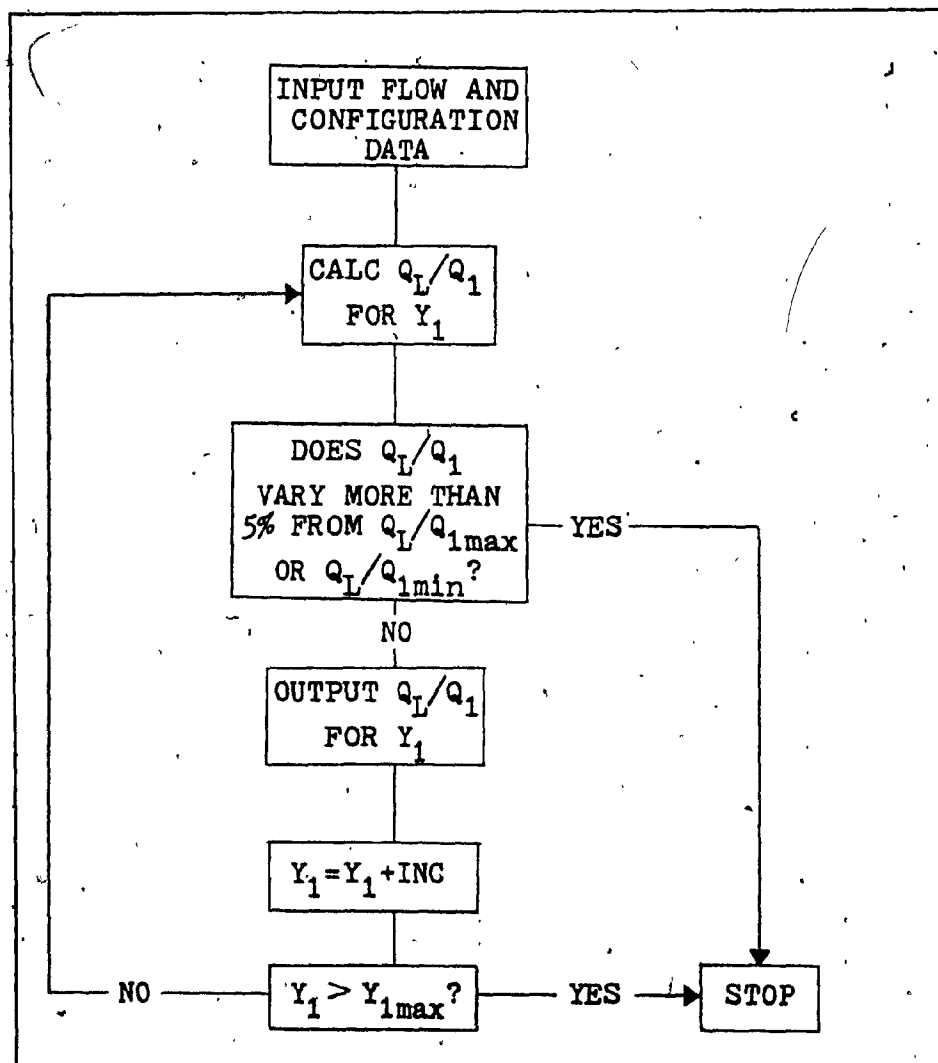


FIGURE 3 ALGORITHM FLOWCHART

34

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COPY RATIOS
0001! COMPUTATIONAL ALGORITHM USED FOR LATERAL WEIR
0002! AND ORIFICE CONFIGURATION. NEIL EVANS 1980
0003!
0004!
0010 EXTEND
0015! SET PARAMETERS
0030 INPUT 'BOT.SILL';BOT.SILL
0040 INPUT 'SLOT';SLOT
0050 INPUT 'MID.SILL';MID.SILL
0051 FOR L.W=.2 TO .76 STEP .05
0052 PRINT '.....L/W=';L.W
0053 VAR.N=0.05
0054 INC=.05
0055 PRINT
0056 PRINT 'L/W BOT SLOT MID'
0057 PRINT USING '###.###.###.###',L.W,BOT.SILL,SLOT,MID.SILL
0060 Y1MAX=1.0
0062! CHECK INPUT
0065 IF (BOT.SILL+SLOT+MID.SILL)>= Y1MAX THEN GOTO 3500
0090! CALCULATE CONSTANTS
0100 C1=-0.538+0.254*L.W
0110 C2=0.058+0.234*L.W
0120 C3=-0.129-0.489*L.W
0130 FOR FR1=.1 TO .9 STEP .1
0133 PRINT
0134 PRINT ' Y1 Q1/Q1 FR'
0135! INITIALIZE HEIGHT OF FLOW
0136 Y1=BOT.SILL+SLOT
0137 SMALL=10
0138 LARGE=0
0140! COMPUTE FLOW RATIO
0150 GOSUB 0500
0210! CHECK VARIATION OF FLOW RATIO
0220 IF ABS((LARGE-SMALL)/LARGE)>=VAR.N THEN GOTO 4000
0223 PRINT USING '###.###.###.###',Y1,Q1,Q1,FR1
0224 IF Q1>1 THEN GOTO 5000
0230! INCREMENT HEIGHT OF FLOW
0231 Y1=Y1+INC
0232 IF Y1>Y1MAX THEN GOTO 3000
0250 GOTO 150
0260! SUBROUTINE TO COMPUTE FLOW RATIO
0500 IF Y1<=(BOT.SILL+SLOT+MID.SILL) THEN GOTO 0520
0510 NW=FR1*SQR(Y1)/SQR(Y1*FR1^2+Y1-BOT.SILL-SLOT-MID.SILL)
0520 IF Y1<=(BOT.SILL+SLOT+MID.SILL) THEN NW=1.0
0530 N1=FR1*SQR(Y1)/SQR(Y1*FR1^2+Y1-BOT.SILL-SLOT)
0540 N2=FR1*SQR(Y1)/SQR(Y1*FR1^2+Y1-BOT.SILL)
0550 G1=0.2037*((N2^3)-(-3))-((N1^3)-(-3))
0560 G2=C1*(1/N2-1/N1)
0570 G3=C2*(N2-N1)
0580 G4=(C3/3.0)*((N2^3)-(N1^3))
0590 J1=(1-NW^3)*(C3/3.0+0.2037/(NW^3))
0600 J2=(1-NW)*(C2+C1/NW)
0610 GJ=G1+G2-G3-G4+J1+J2
0620 Q1=(2.0*L.W*FR1^2)*GJ
0630 IF Q1<SMALL THEN SMALL=Q1
0631 IF Q1>LARGE THEN LARGE=Q1
0640 RETURN
0650! TERMINATING STATEMENTS
3000 PRINT
3100 GOTO 5000
3500 PRINT 'NO HEAD FOR WEIR'
3600 GOTO 5100
4000 PRINT
4050 PRINT 'EXCESSIVE VARIATION'
5000 NEXT FR1
5001 NEXT L.W
5050 PRINT
5100 PRINT TIME(12)
6000 END

```

READY

FIGURE 4 RATIOS ALGORITHM

```

COPY RATIO
0001! COMPUTATIONAL ALGORITHM USED FOR LATERAL
0002! WEIR AND ORIFICE CONFIGURATION.
0003! NEIL EVANS 1980
0004!
0010 EXTEND
0023! SET PARAMETERS
0026 DELTA.FR1=.001
0027 DELTA.QLQ1=.01
0030 INPUT 'BOT';BOT.SILL
0035 INPUT 'SLOT';SLOT
0040 INPUT 'MID';MID.SILL
0042 INPUT 'FR1';FR1
0043 FOR L.W=.2 TO .9 STEP .2
0044 FOR DESIGN=.2 TO .9 STEP .2
0045 INC=.1
0060 Y1MAX=1.0
0065 IF (BOT.SILL+SLOT+MID.SILL)>= Y1MAX THEN GOTO 3500
0080 VAR.N=.05
0090! CALCULATE CONSTANTS
0100 C1=-0.538+0.254*L.W
0110 C2=0.058+0.234*L.W
0120 C3=-0.129-0.489*L.W
0133 PRINT 'L/W=';L.W
0134 PRINT ' Y1 QL/Q1 FR'
0135! INITIALIZE HEIGHT OF FLOW
0136 Y1=BOT.SILL+SLOT
0137 Y1.INITIAL=Y1
0140! COMPUTE FLOW RATIO
0150 GOSUB 0500
0224 PRINT USING '##.## ##.## #.###',Y1,QLQ1,FR1
0230! INCREMENT HEIGHT OF FLOW
0231 Y1=Y1+INC
0232 IF Y1>Y1MAX THEN GOTO 5050
0249 GOTO 150
0500! SUBROUTINE FOR FLOW RATIO
0505 IF Y1<=(BOT.SILL+SLOT+MID.SILL) THEN GOTO 0520
0510 NW=FR1*SQR(Y1)/SQR(Y1*FR1^2+Y1-BOT.SILL-MID.SILL)
0520 IF Y1<=(BOT.SILL+SLOT+MID.SILL) THEN NW=1.0
0530 N1=FR1*SQR(Y1)/SQR(Y1*FR1^2+Y1-BOT.SILL-SLOT)
0540 N2=FR1*SQR(Y1)/SQR(Y1*FR1^2+Y1-BOT.SILL)
0550 G1=0.2037*((N2^(-3))-(N1^(-3)))
0560 G2=C1*(1/N2-1/N1)
0570 G3=C2*(N2-N1)
0580 G4=(C3/3.0)*((N2^3)-(N1^3))
0590 J1=(1-NW^3)*(C3/3.0+0.2037/(NW^3))
0600 J2=(1-NW)*(C2+C1/NW)
0610 GJ=G1+G2-G3-G4+J1+J2
0620 QLQ1=(2.0*L.W*FR1^2)*GJ
0624 IF ABS((QLQ1-DESIGN)/DESIGN)<=DELTA.QLQ1 THEN GOTO 0640
0625 IF QLQ1<DESIGN THEN FR1=FR1+DELTA.FR1
0626 IF QLQ1>DESIGN THEN FR1=FR1-DELTA.FR1
0629 GOTO 0505
0640 RETURN
0650! TERMINATING STATEMENTS
3500 PRINT 'NO HEAD FOR WEIR'
3600 GOTO 5100
4000 PRINT 'EXCESSIVE VARIATION'
5050 PRINT
5100 PRINT TIME(1Z)
5200 NEXT DESIGN
5300 NEXT L.W
6000 END

```

READY

FIGURE 5 RATIO ALGORITHM

RUN RATIO
 BOT? .1
 SLOT? .45
 MID? .1
 L/W? .4
 DESIGN FLOW RATIO? .5
 L/W= .4

| Y1 | QL/Q1 | FR |
|-----|-------|-------|
| 0.6 | 0.50 | 0.237 |
| 0.7 | 0.50 | 0.231 |
| 0.8 | 0.50 | 0.231 |
| 0.9 | 0.50 | 0.232 |
| 1.0 | 0.50 | 0.237 |

29

READY

RUN RATIO
 BOT? .1
 SLOT? .45
 MID? .1
 L/W? .6
 DESIGN FLOW RATIO? .2
 L/W= .6

| Y1 | QL/Q1 | FR |
|-----|-------|-------|
| 0.6 | 0.20 | 0.812 |
| 0.7 | 0.20 | 0.812 |
| 0.8 | 0.20 | 0.812 |
| 0.9 | 0.20 | 0.814 |
| 1.0 | 0.20 | 0.828 |

67

READY

RUN RATIOS
 BOT.SILL? .1
 SLOT? .45
 MID.SILL? .1
 L/W? .2
L/W= .2

| L/W | BOT | SLOT | MID |
|------|------|------|------|
| 0.20 | 0.10 | 0.45 | 0.10 |

| Y1 | QL/Q1 | FR |
|------|-------|-----|
| 0.55 | 0.598 | 0.1 |
| 0.60 | 0.596 | 0.1 |
| 0.65 | 0.581 | 0.1 |
| 0.70 | 0.577 | 0.1 |
| 0.75 | 0.580 | 0.1 |
| 0.80 | 0.586 | 0.1 |
| 0.85 | 0.593 | 0.1 |
| 0.90 | 0.599 | 0.1 |
| 0.95 | 0.606 | 0.1 |

| Y1 | QL/Q1 | FR |
|------|-------|-----|
| 0.55 | 0.190 | 0.3 |
| 0.60 | 0.190 | 0.3 |
| 0.65 | 0.186 | 0.3 |
| 0.70 | 0.184 | 0.3 |
| 0.75 | 0.185 | 0.3 |
| 0.80 | 0.187 | 0.3 |
| 0.85 | 0.189 | 0.3 |
| 0.90 | 0.191 | 0.3 |
| 0.95 | 0.193 | 0.3 |

| Y1 | QL/Q1 | FR |
|------|-------|-----|
| 0.55 | 0.106 | 0.5 |
| 0.60 | 0.107 | 0.5 |
| 0.65 | 0.105 | 0.5 |
| 0.70 | 0.104 | 0.5 |
| 0.75 | 0.105 | 0.5 |
| 0.80 | 0.105 | 0.5 |
| 0.85 | 0.106 | 0.5 |
| 0.90 | 0.108 | 0.5 |
| 0.95 | 0.109 | 0.5 |

FIGURE 6 SAMPLE PARTIAL OUTPUT

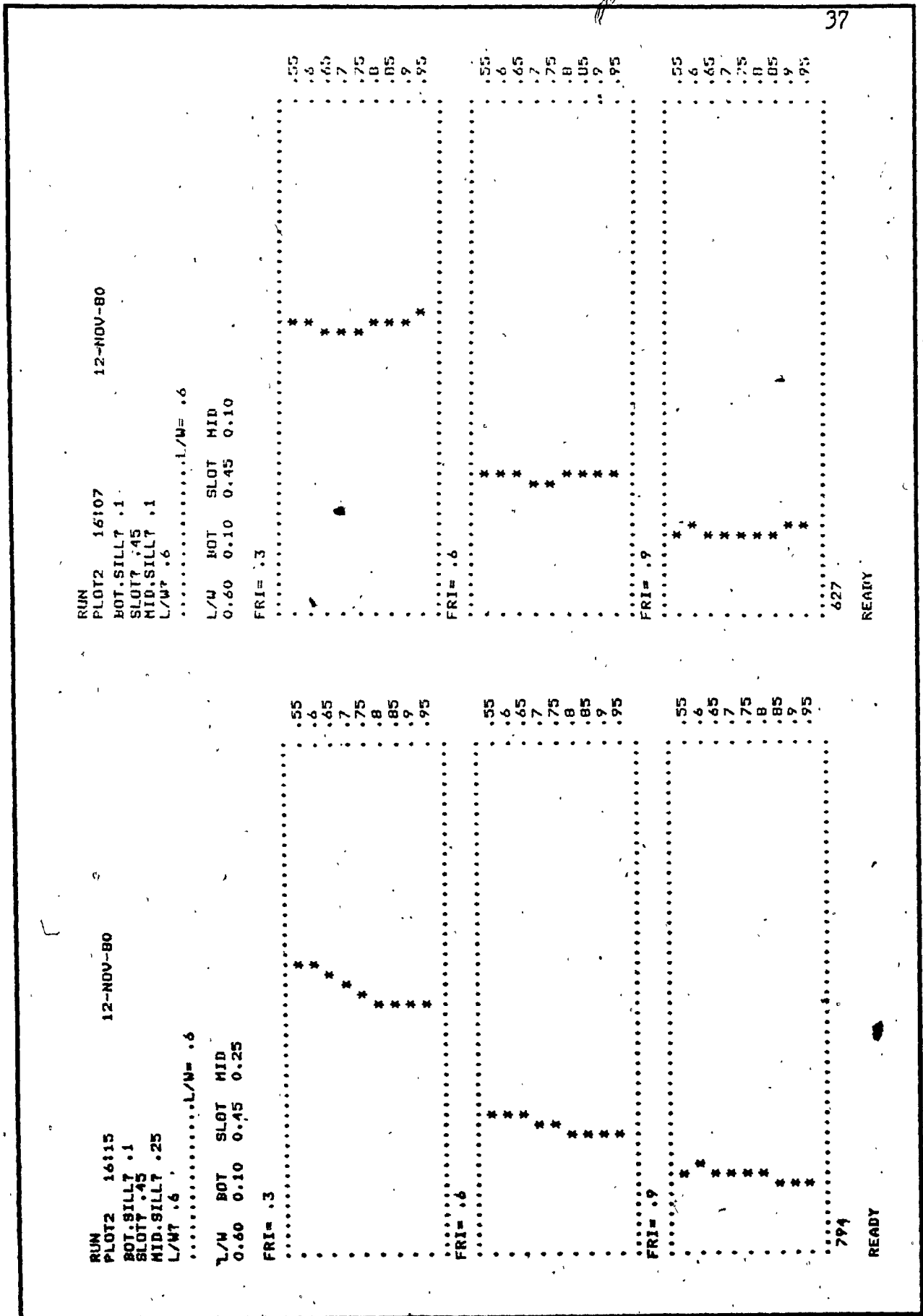


FIGURE 7 COMPARISON PLOT

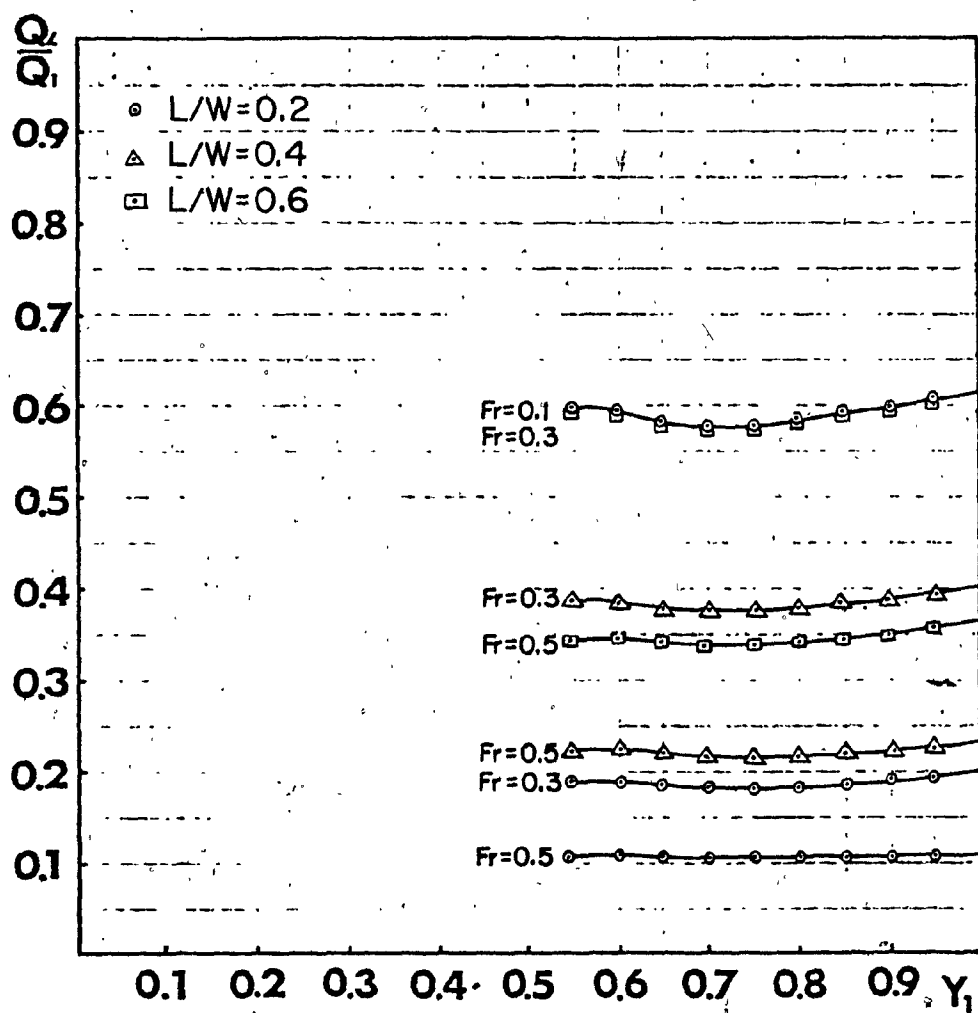


FIGURE 8 Q_L/Q_1 VS Y_1 FOR SELECTED CONFIGURATION

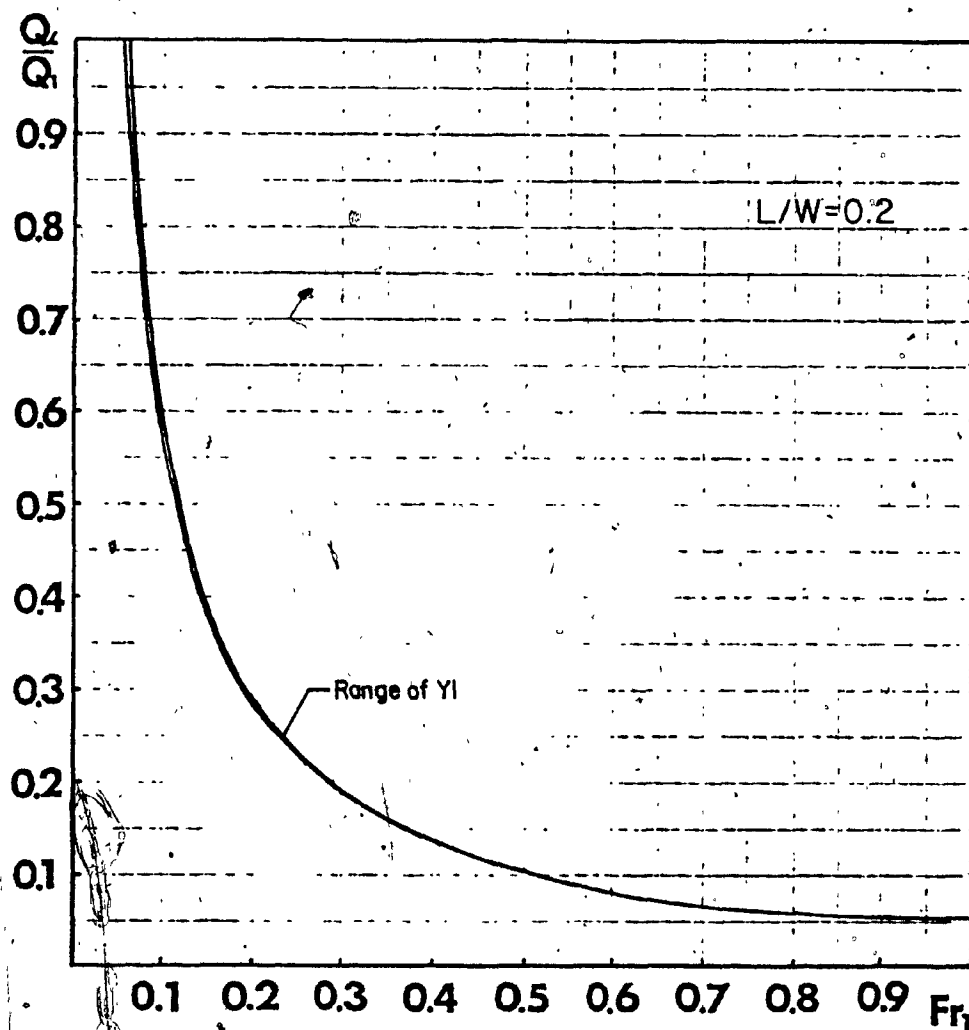


FIGURE 9 Q_1/Q VS Fr_1 FOR SELECTED CONFIGURATION

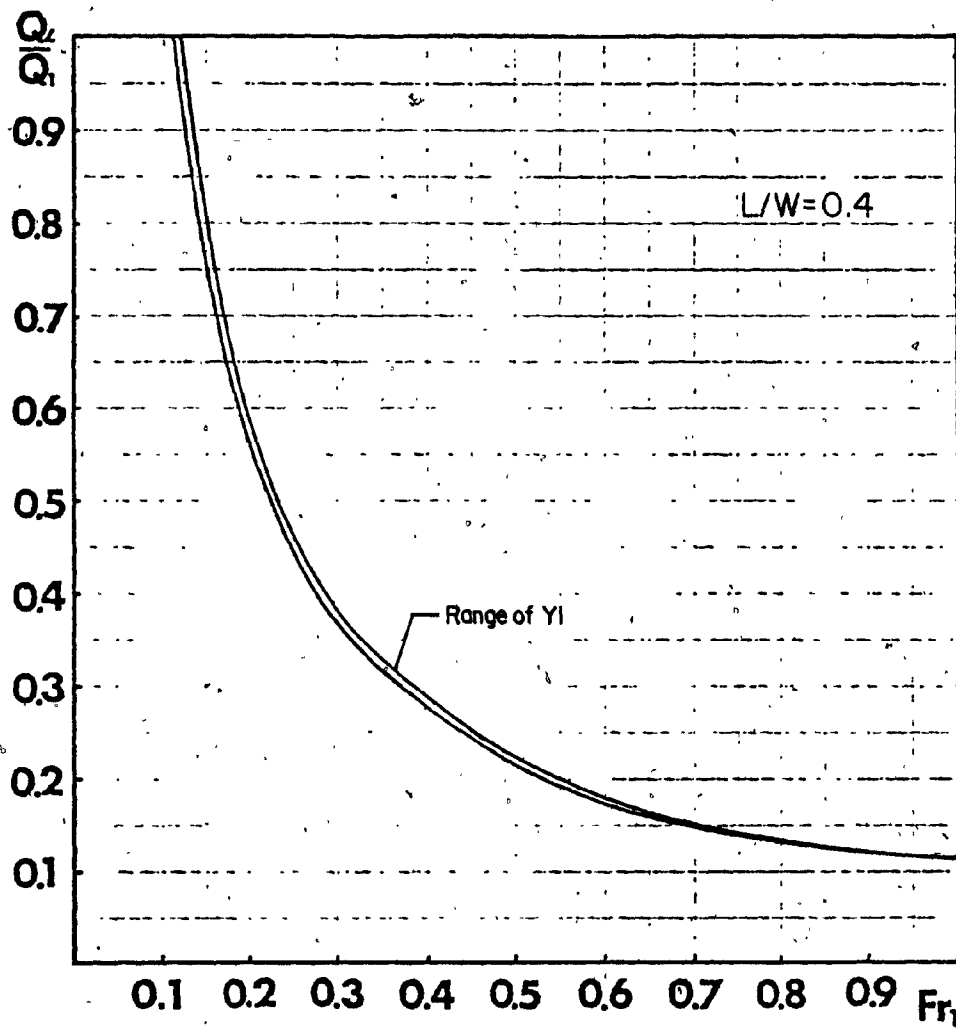


FIGURE 10 Q_L/Q_1 VS Fr_1 FOR SELECTED CONFIGURATION

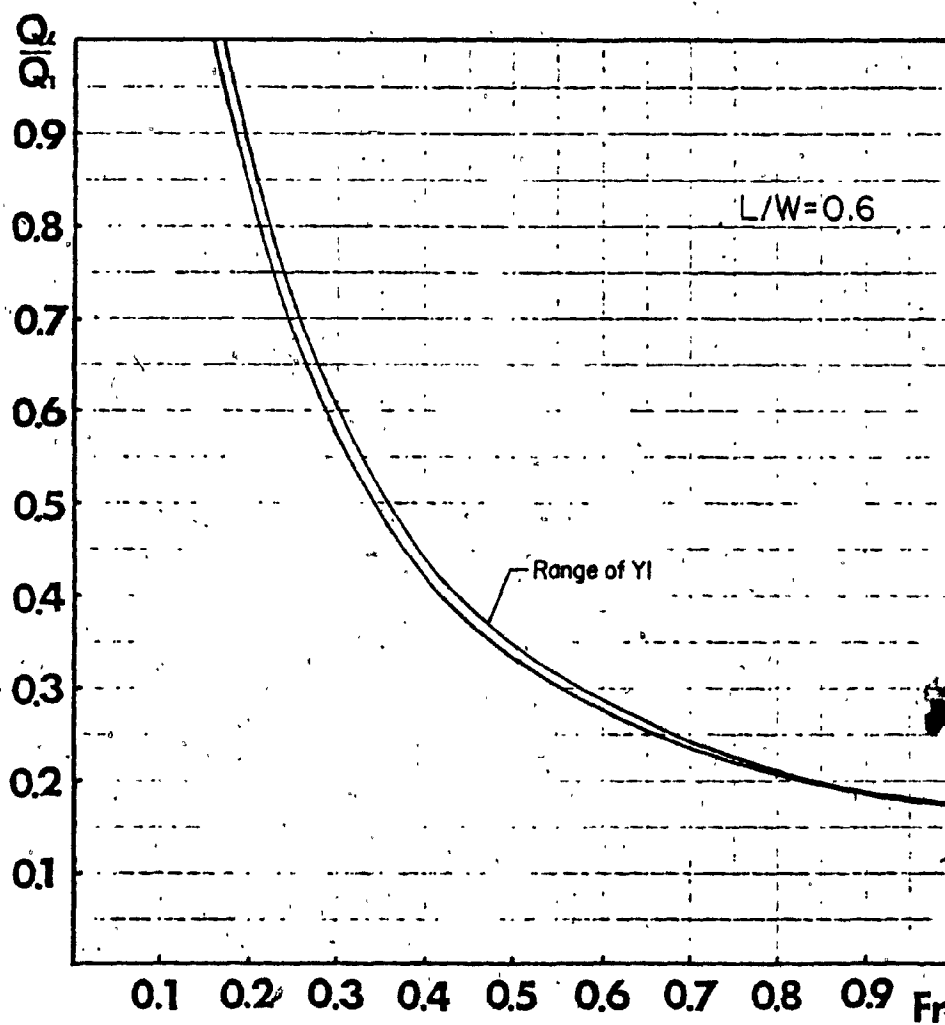


FIGURE 11 Q_L/Q_1 VS Fr_1 FOR SELECTED CONFIGURATION

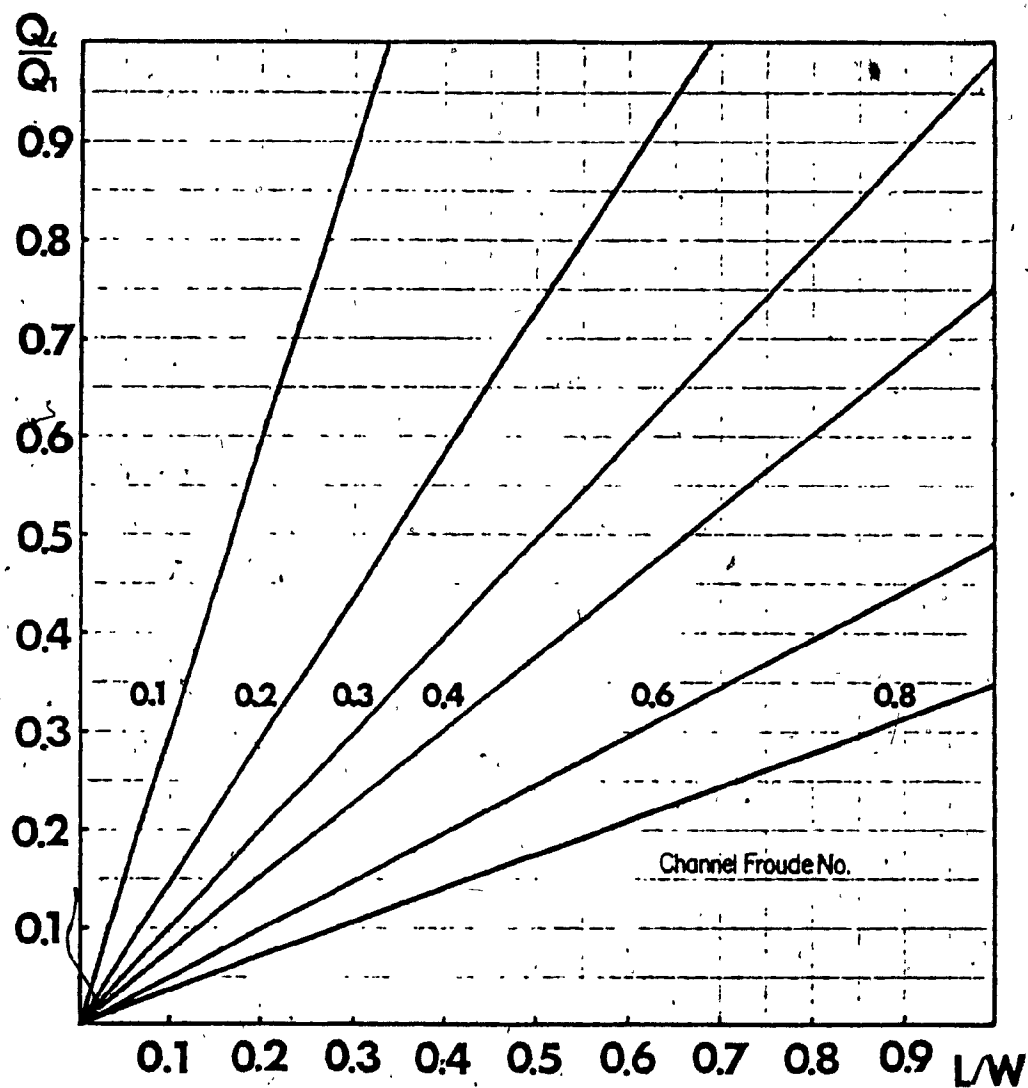


FIGURE 12 DESIGN CHART

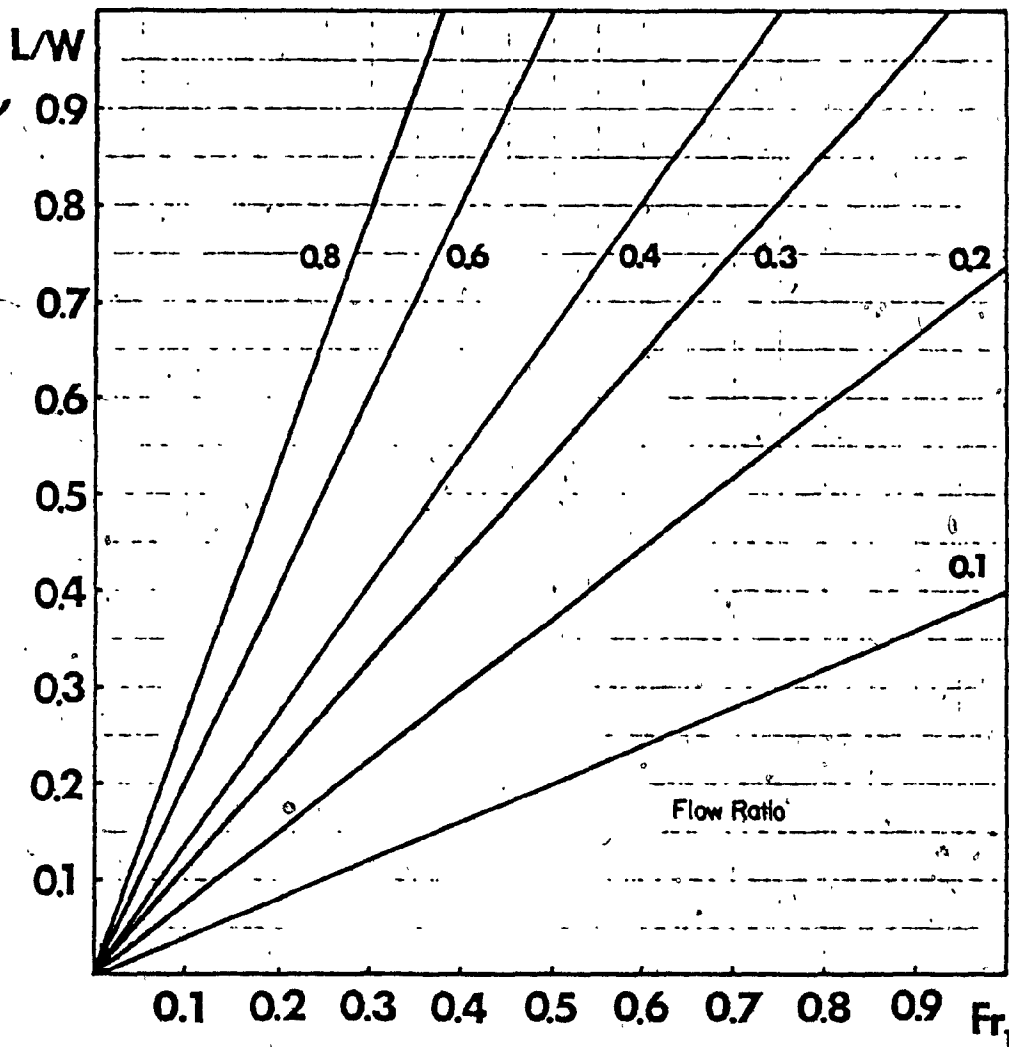


FIGURE 13 DESIGN CHART

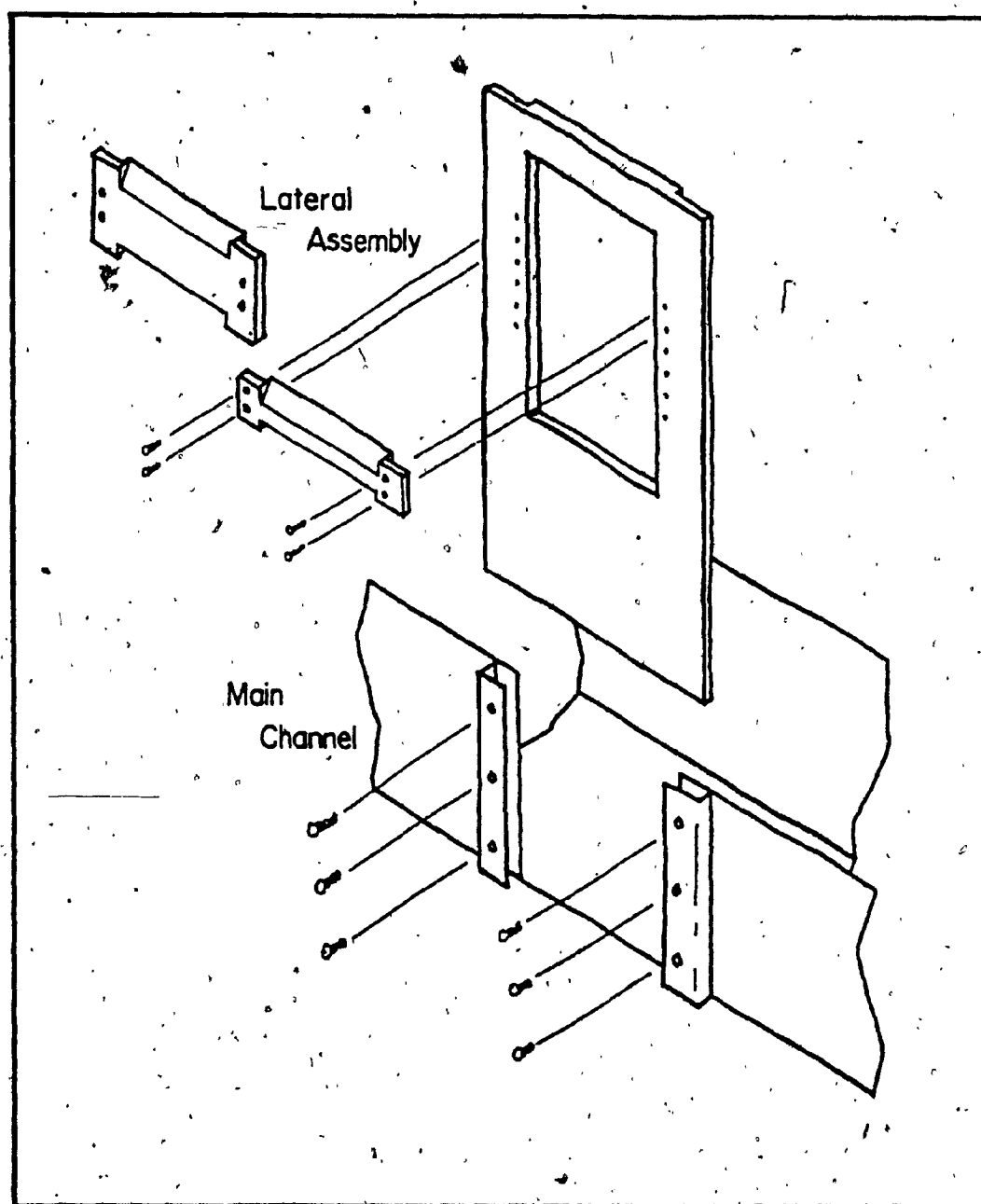
APPENDIX C
EXPERIMENTAL SET-UP

APPENDIX C

EXPERIMENTAL SET-UP

The theoretical flow ratio relationship derived in Chapter II may easily be verified through the use of the following equipment:

- i) A main channel capable of carrying varying flows of 0.5 to 2.5 cfs.
- ii) Two V-notch weirs to be used to accurately measure Q_L and Q_1 . For small flows, a scale and container may be used.
- iii) A lateral constructed in such a manner as to facilitate the varying of the previously discussed geometric parameters. Figure 14 illustrates a possible design. L/W may be varied by constructing 3 or 4 of these lateral, each of different length.
- iv) A channel insert to impose the contraction necessary for the horizontal free surface condition. This insert might be constructed of plexiglas and fashioned to allow adjustment for various flow conditions, (See Chapter II).



POSSIBLE DESIGN OF EXPERIMENTAL SET-UP

FIGURE 14